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Climate impact assessment in the Great Lakes Basin

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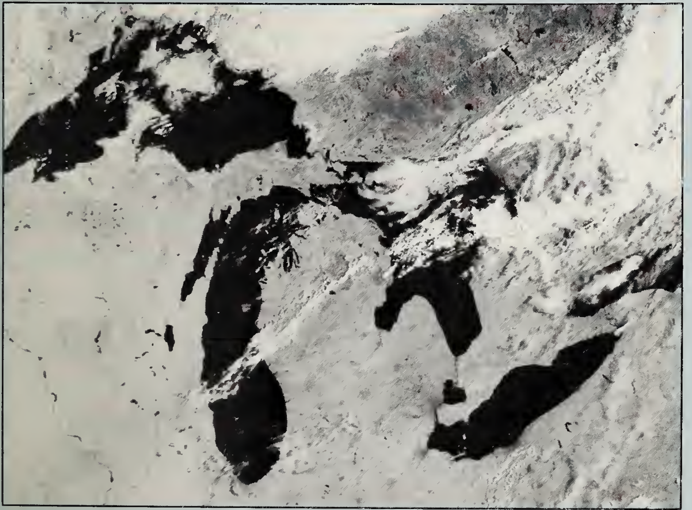
ENVIRONMENTAL MONOGRAPH NO. 7

Climate Impact Assessment In the Great Lakes Basin:

Overview and Research Recommendations

Edited by
Peter Timmerman and A.P. Grima



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Climate Impact Assessment in the Great Lakes Basin: Overview and Research Recommendations

From a Canadian Climate Program Workshop,
8–9 February 1985

Edited by Peter Timmerman
and A.P. Grima

Institute for Environmental Studies
University of Toronto Toronto, Canada M5S 1A4

November 1985 Pub. No. EM-7

ISBN 0-7727-4408-4
ISBN 0710-6815

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EXECUTIVE SUMMARY

The potential impacts of a CO_2–induced climate warming on the physical, biophysical, and socio-economic systems of the Great Lakes Basin was the focus of a Canadian Climate Program Workshop held February 8–9, 1985 at Seneca College, King City, Ontario. While there is as yet no final agreement on the detailed scenarios for the future climate in this region, the consensus is that there will be a general warming trend which will have varied and diverse impacts. The Workshop concluded that, given the urgency of the issue and the state of present knowledge, a coherent research strategy would assist in the formulation of overall policies that could minimize potentially adverse effects and maximize potentially beneficial effects.

Elements of this research strategy would include:

- improving the resolution of climate scenarios derived from general circulation models;
- supporting research into the climate parameters affecting Great Lakes levels, and the modelling of atmosphere-lake interactions;
- supporting research into the response functions of biological systems to various parameters of climate change;
- assigning high priority to socio-economic research that both identifies sector-by-sector expressions of climate impact, and begins to develop integrating frameworks that will more realistically capture the complexities of socio-economic systems;
- recognizing and enhancing the contributions of the above elements by improving the policy-making aspects of the climate warming issue through the fostering of relevant administrative structures, institutional arrangements, and the widest possible dissemination of information relating to climate impacts;
- ensuring the efficiency of proposed future research by encouraging interdisciplinary research through "networking" and other forms of information exchange.

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FOREWORD

In the past few years, a scientific consensus has emerged that we are about to experience a significant warming of the world's climate due to the effects of the increased release of carbon dioxide (CO_2) and other gases into the atmosphere. The rate of degree of the warming is still in question, as are the consequences of this warming for the well-being of the peoples of the Earth.

The potential consequences of this significant warming are so large, however, that international organizations such as the World Meteorological Organization (WMO), and the United Nations Environment Program (UNEP), have expressed their concern through a series of conferences, resolutions and support for global research into this issue. The National Academy of Sciences (NAS), and the Environmental Protection Agency (EPA) in the U.S. have produced thorough reviews of current research into the CO_2 problem.

In Canada, the Canadian Climate Program – a national program including federal and provincial agencies, universities, and the private sector with the Atmospheric Environment Service, Environment Canada as the lead agency – has been the focus for climate-related research, with a Climate Impacts Program operating under its auspices to look particularly at the socio-economic implications of climate variability and long-term climate change. Its priority sectors to date have been the implications of climate change for food production in Ontario and the Prairie Provinces, and the implications of climate change for the Great Lakes Basin as a whole.

These regional studies represent the "second generation" of impact studies following on from the global reports mentioned above, and the similar wide-ranging general methodological treatments of the subject of climate impact assessment (e.g. the 1985 SCOPE (27) volume "Climate Impact Assessment: Studies of the Interaction of Climate and Society" edited by Kates, Ausubel and Berberian). They attempt to clarify potential climate impacts below the global level and above the short-term, local, immediate impacts of severe weather events such as early frosts or tornadoes. It is at the regional level that policies relating to management of the problem can begin to operate most effectively, and where the interdisciplinary research necessary to proper investigation of climate impacts can be applied most appropriately.

The Great Lakes Basin provides a perfect testing ground for these regional impact studies. Among other attributes, it provides:

- a globally significant natural ecosystem;
- a hundred-year data base;
- a complex jurisdictional structure;
- a highly developed socio-economic system closely integrated with the natural ecosystem of the Basin.

This integration of natural and socio-economic systems in a single region and the important social and political implications of issues such as increased consumptive water use and proposed diversions prompted the Canadian Climate Program to sponsor a Workshop on *Climate Impact Assessment in the Great Lakes Basin: Research Strategies* which was held 8-9 February 1985 at Eaton Hall, Seneca College, King City, Ontario. The program of the Workshop is in Appendix 1, and Appendix 2 lists the 50 participants. The Workshop opened with keynote addresses, dealing with the general field of climate impact assessment, by Dr. William E. Riebsame of the University of Colorado and Dr. Martin Parry of the International Institute for Applied Systems Analysis (IIASA), Austria. Then followed a series of research overviews focussing on the Great Lakes basin, including keynote speeches by Mr. Stan A. Changnon (Illinois State Water Survey) and Dr. F. Kenneth Hare, University of Toronto. These presentations set the stage for five concurrent sessions dealing with the following topics:

- Climate scenarios (H.G. Hengeveld, rapporteur);
- Effects of climate on physical systems in the Great Lakes Basin (M. Sanderson and F. Quinn, rapporteurs);
- Effects of climate on ecological systems in the Great Lakes Basin (H.A. Regier and W. Baker, rapporteurs);
- Effects of climate on socioeconomic systems in the Great Lakes Basin (P. Timmerman and A.P. Grima, rapporteurs);
- Public policy with respect to the effects of climate on the Great Lakes (G.A. McKay and H.E. Turner, rapporteurs).

At the final plenary session, the reports of the discussion groups were accepted in principle. Subsequently, the participants had an opportunity to read and comment on the draft reports.

The Workshop was organized by the Institute for Environmental Studies (IES), University of Toronto under the leadership of R.E. (Ted) Munn. A Steering Committee helped in designing the program and in providing advice on the publication of this volume. Members of the Committee include:

R.E. Munn, IES (Co-Chairman)
A.P. Grima, IES/Geography (Co-Chairman)
J. Hall, Wilfrid Laurier University
G.A. McKay, Toronto
D.W. Phillips, Atmospheric Environment Service

H.A. Regier, IES/Zoology
M. Sanderson, University of Windsor
J. Sandilands, Atmospheric Environment Service
P. Timmerman, IES.

In consultation with Workshop participants, the Steering Committee decided that the proceedings of the Workshop should be edited for publication. The importance of the issues raised required the earlier publication of a short overview and the groups' recommendations for research. F. Kenneth Hare's address to the Workshop, as revised for the volume of proceedings, seemed to the committee and editors as particularly appropriate to serve as an initial overview to the issue of climate impacts on the Great Lakes Basin and we are pleased to be able to present it here.

The Editors are indebted to their colleagues on the Steering Committee for their advice. They are particularly indebted to R.E. Munn who chaired the Workshop and led the project until he moved to IIASA in March 1985. Finally and most importantly, we acknowledge the administrative assistance of Ms. Gail Rania, who single-handedly kept the Workshop from foundering.

PART ONE

Climate Impact in the Great Lakes Basin: An Appraisal

Climate Impact in the Great Lakes Basin: An Appraisal

F. Kenneth Hare
(Provost of Trinity College, Toronto)

Address before the Workshop
on Climate Impact Assessment in the
Great Lakes Basin: Research Strategies

PREAMBLE

This opening paper will attempt a qualitative appraisal of the Great Lakes Basin itself, and of the points of contact between climate and the human economy within the Basin. The scientific method stresses quantitative experiments, and these have indeed been attempted by some of the contributors to this volume. But political judgements are in the last analysis qualitative, in the literal sense of that word. They depend on appraisals of the body of evidence, and on a sense of what is important to the various electorates.

In appraising these matters for the Great Lakes Basin one cannot separate land and water. The human beings that put pressure on the Lakes live on the land. They use the water to the full, for a variety of purposes. Their activities on land dictate the level of that use, and also affect the quality of water. So the analysis must extend to the whole Basin – indeed to the whole St. Lawrence system above tidewater.

The entire question of water management in this huge basin is complicated by jurisdictional hang-ups – by an international boundary that splits the basin not unequally, but leaves most of the people and political clout on the U.S. side; and by state and provincial governments whose performance has a great deal to do with the success of management programmes. Nature put the Great Lakes Basin together. Human caprice has done a lot to take it apart.

THE BASIN

The Basin is truly extraordinary. It is like no other hydrographic system on earth. It lies straddled across the border between the Canadian Shield and the sedimentary basin of the Mid-west and Great Plains. Below Montreal the Appalachian system presses in against the St. Lawrence Lowlands, which are separated from southern Ontario by a low ridge of the Shield – the Frontenac

Axis – that forms the link between the Haliburton Highlands, Algonquin Park and the Adirondacks. The Axis shows up to the St. Lawrence as the rock knobs of the Thousand Islands and the surrounding countryside of New York and Ontario.

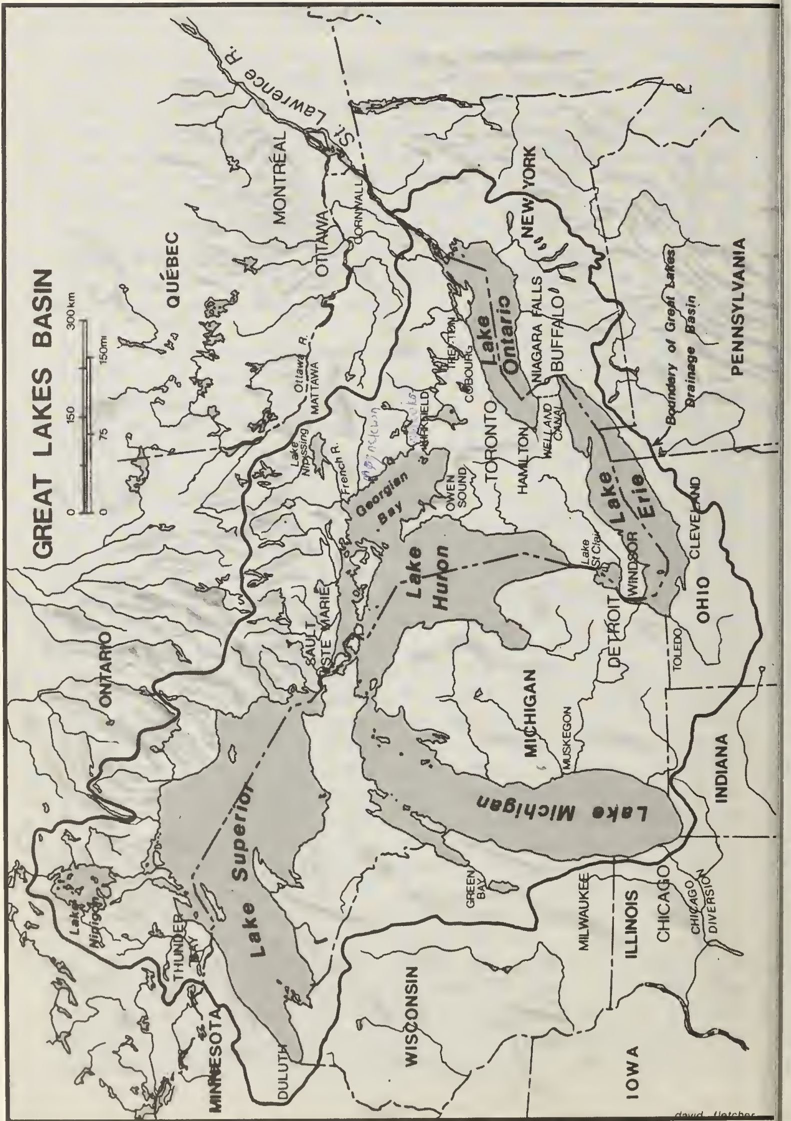
Out of this broad geological transition zone, erosion – glacial and riverine – carved the huge hollows occupied by the Great Lakes. Successive glaciations in Pleistocene time – the past 2 million years – did much of the work. The most recent glaciers also deposited extensive morainic and outwash material upon the surface. As this ice receded it created successive lakes in the hollows it exposed, some of them larger than their modern equivalents, others temporary ponding on what is now dry land. The shorelines of these late-Glacial and early Holocene Great Lakes are known to all local residents – the massive cliffs and beaches of Lake Iroquois, for example, followed by Davenport Road in Toronto, and by Highway 401 between Cobourg and Trenton. As the lakes shrank into their present basins they exposed the fertile lake bottom clays on which Ontario's best farmland is located.

They also used a variety of spillways for the water to escape to the oceans. For a time the early Lake Superior drained to the Mississippi past Duluth-Superior, as did Green Bay to the Wisconsin. The early Michigan drained via what is now the Chicago drainage canal to the Illinois. Erie and Huron went via the Wabash to the Ohio. Lake Iroquois, the ancestor of Lake Ontario, drained via the Mohawk to the Hudson, the modern route of the Erie Canal, the former New York Central main rail line, and the New York State Thruway. There was for a while drainage via Kirkfield from Huron and Georgian Bay into the Trent River system. The Nipissing Great Lakes, the enlarged most recent ancestor of the Upper Great Lakes, used the French River, Lake Nipissing and the Mattawa River to reach the Ottawa, and thence the Plain of Montreal. The combined waters of the St. Lawrence and Ottawa carved out many channels and cut many bluffs (*les côteaux* of the Québec settlers) out of the soft marine clays left by the Champlain Sea.

These cliffs, shorelines and spillways have had an extraordinary impact on the human economy,on social history, and even on warfare. Greatest of all is the gorge of the Niagara River, now taking the full flow of the Upper Lakes, but less impressive at various earlier times than today. Many of the abandoned spillways were used as canoe routes, the Nipissing trench being the westward route from Montréal for the North West Company. The only existing major diversion out of the Great Lakes Basin uses the old Chicago spillway. In short, the past fifteen thousand years of evolution of the Lakes have presented humanity with endless challenges and opportunities.

Considering the Basin to end at the Iroquois Control Dam on the St. Lawrence, its modern area is 755,200 km^2, of which 538,900 km^2 are land, and 216,300 km^2 are lake surface. The portion of water – 29 per cent – is unique for such a large basin. 40,000,000 people are resident, not far from the population of France. The Lakes are the world's largest inland waterway, provide huge hydroelectric sites, and offer drinking water, industrial supplies, irrigation and recreation to one of the world's most industrialized regions. The outflow

Figure 1. The Great Lakes Basin



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of water – the annual average at Barnhart Island (Ontario Hydro's station above Cornwall) is 7,190 cubic metres per second (cms) – is about 7 per cent of Canada's total discharge to the ocean. At Montréal, after the confluence with the Ottawa, the figure rises to 9,650 cms about 90 per cent of the discharge of the Mackenzie into the Arctic Ocean. The 1,026,000 km^2 of the entire St. Lawrence-Great Lakes Basin discharges 9,860 cms, equivalent to 300 mm of rainfall (Canadian Committee for the International Hydrological Decade, 1969; K.D. Harvey, personal communication).

This, then, is the vast natural system whose well-being is now threatened by two things: excessive use of its waters by the human population, and probable climatic change (Foster & Sewell, 1982; Hare, 1984a).

THE CLIMATE

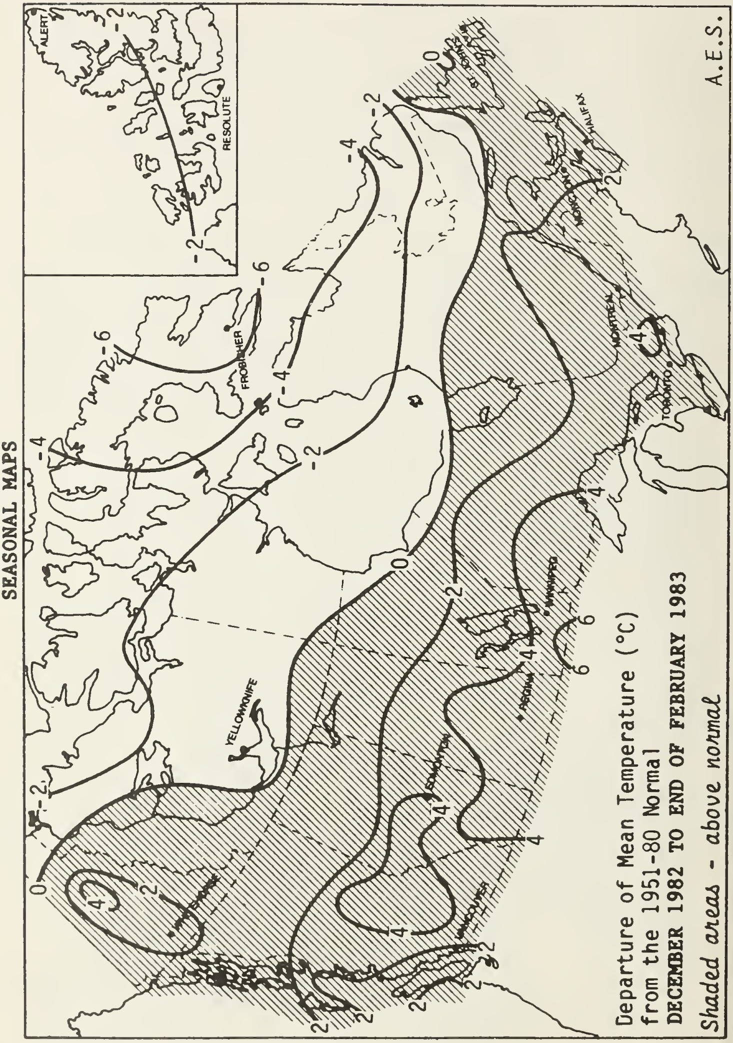
The entire basin lies within the same broad climatic region of North America. For much of the year it lies below the typical position of the mid-latitude jet stream in the circumpolar westerly winds. A strong south to north temperature gradient is a feature of all but the mid-summer period. The unstable westerlies and their disturbances drive a succession of rain-bearing cyclonic storms across the Basin, which has substantial rainfall or snowfall in all seasons. Annual precipitation varies from 550 to a little over 1,000 mm. Whatever the anomalies in the structure of the westerlies, it is probable that precipitation will fall frequently in the Basin. Drought is unusual, and when it occurs it is usually fairly local. It rarely extends across the whole Basin for long. Further downstream, in the lower St. Lawrence and around the Gulf, the reliability of mean annual precipitation rises to its highest known level – a coefficient of variation of only 10–15 per cent.

High on the list of special climatic factors is the annual freeze-thaw cycle in lakes and rivers, and the formation and dissolution of winter snow-cover. Both have large economic consequences. Small changes in either can yield heavy costs or high benefits. The ice régime in the rivers is important to loggers and power operators. In the Lakes it defines the navigation season. Snowcover is crucial to woods operators, and important to farmers. It is white gold to the power industry. It has high ecological importance to wildlife.

Future climatic change will probably affect the magnitude and timing of both aspects of the temperature cycle. A mid-winter rise of 5 deg C, possible from the combined infrared greenhouse effect of carbon dioxide and other absorbers by 2050 A.D. (Hare, 1984b) would eliminate the ice-cover from most of the lakes, and greatly shorten and thin out the snowcover. In fact southern Ontario would lack a continuous cover in winter seasons.

Even today the milder winters tend to rehearse the potential effects of true climatic change. The winter of 1982–83, perhaps the warmest ever, was a spectacular case related to the El Niño-Southern Oscillation event in the Pacific. Over the whole Great Lakes-St. Lawrence System from Montréal to Duluth, Chicago and Toledo, mean winter temperatures were 3–4 deg C above normal and as much as 6 deg C in southernmost Manitoba (Figure 2).

Figure 2. Winter 1982–1983: Temperature regime over Canada



Little ice formed in the Lakes, except in sheltered waters, and snowcover was intermittent or largely absent in most farming areas. The event was unpredicted, and hence had less effect on navigation than might otherwise have been expected; but at least we saw, in concrete detail, what the ordinary winter might be like five to ten decades from now.

A further noteworthy aspect of the Basin's climate is its proneness to violent weather. In spring and summer all parts of the Basin are subject to severe thunderstorms, some of which develop into damaging tornadoes. The risk is highest in the Michigan, Huron and Erie basins, but extends even into the Montréal plain and Ottawa valley. The coldness of the Lakes generally reduces the intensity of severe weather over the water, but effects are occasionally devastating over small areas of land. Vastly more dangerous on the Lakes are the severe cyclonic storms of the colder months, especially November and December, when shipping is still active. Many vessels have been lost, even though only a few cyclones become violent in the course of a year. Major storm surges may occur in Lake Erie, leading to flooding; and lake ice, driven by gale-force winds, may do severe damage to shoreline properties, notably on Lake St. Clair. A curious feature of the system is that Lake Erie, the southernmost and shallowest member, is the most prone to all these kinds of violent weather, and to heavy ice damage.

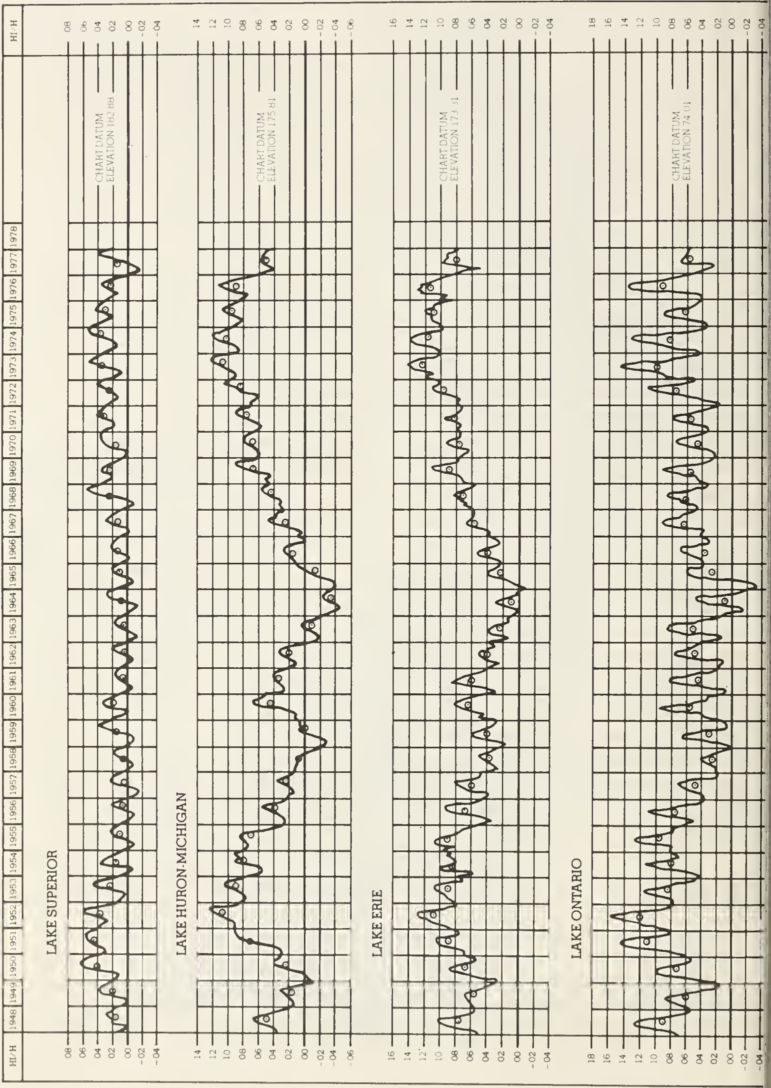
A final special aspect of the climate is the generation of lake-effect snowfall. When cold Arctic air streams south-eastward across Lakes Superior and Huron, eastward along Ontario and Erie, and southward over Michigan, the warmth of the remaining open water (usually nearly 100 per cent in the case of Ontario) causes rapid evaporation, and creates banks of shallow but turbulent cumulus cloud. As they move inland these clouds dump large amounts of low-density snow. The Huron and Georgian Bay shores, the eastern and southern shores of Lake Ontario, and the south-eastern shores of Lake Erie have great snow belts that accumulate deep snowcover. The effect does not as a rule extend far inland. These snowbelts are the major ski areas of their respective jurisdictions, and have high winter cash incomes in good years. Mild winters are economically disastrous (Dewey, 1979) to the operators of the ski business.

All these details of the climate of the Basin are likely to alter substantially if the expected greenhouse effect actually works. Hence the importance of the papers delivered at this Workshop to the economic future of the region – to say nothing of the Lakes themselves, and the valuable ecosystems that they contain.

WATER LEVELS AND SHORELINE PROCESSES

Water levels in all the lakes are subject to significant periodic and quasi-periodic variation, whose origin is for the most part (Figure 3) climatic. There is a regular annual cycle, larger in Lake Ontario than in the lakes above Niagara. There is a slow variation of highest amplitude in Huron-Michigan-Georgian Bay (a single water body hydrographically) with average period

Figure 3.
The fluctuating water levels of the Great Lakes system
(Courtesy Ontario Ministry of Natural Resources)



about 20 years. This tendency is only faintly visible in Lake Superior's record. Substantial short-term variations due to travelling storms are superimposed on these quasi-periodic effects. If storm surges or ice ridges affect shorelines at time of generally high water, substantial erosion and damage to property may occur (Ontario Ministry of Natural Resources, 1981).

Water levels are also important because of their close relation to discharge, and hence to power generation. They are crucial to amenity and recreation. At the low-water point of the mid-sixties the water retreated hundreds of meters from some of the beaches and limestone shores of Lake Huron, and significant navigational problems occurred in shallower waters, locks and certain harbours. Hence it is important to ask: what is the measure and nature of climatic control over this variation?

I am not sure of this subject, and hope that someone else can explain the relationship in detail. Clearly precipitation, evaporation, run-off and discharge affect lake levels. The latter's enormous capacity – Superior's annual discharge is only one two-hundredth of its storage – buffers short-term effects, and produces lags in response to climatic forcing.

This apparent 20-year rhythm, which is not truly periodic, resembles rainfall fluctuations in the upper Mississippi and Missouri basins to the west. These have now been shown quite conclusively to be quasi-periodic, and not to be dependent on the 22-year Hale sunspot cycle (Stockton and Meko, 1983; Oladipo, 1982). It would be useful to carry out similar analyses of the rainfall-snowfall record in the Great Lakes Basin, where cool-season precipitation is much more important than in the Mississippi-Missouri basin. Meanwhile it is certainly unsafe to rely on the apparent 20-year rhythm in lake levels.

Consumptive uses and diversions also threaten present water levels. Water that is withdrawn and returned – more than nine-tenth of the withdrawals *do* return – affects neither water-levels nor discharge. But water that is used to cool thermal electric plants (the dominant use), or to irrigate fields, is largely evaporated. Apart from a few showers that may return water to the system, consumptive use of this kind is a loss to liquid throughput. Bruce (1984) has estimated that the loss of discharge from the Great Lakes from such consumptive uses – mostly on the U.S. side – may be almost 9 per cent by the end of this century.* Although such losses are primarily due to U.S. development, the effect is felt equally on both sides of the Lakes.

Much larger effects on water levels and discharge have been predicted as the result of climatic change. Bruce's (1984) estimate is that variation in precipitation and evaporation induced by the greenhouse efect may decrease discharge by 21 per cent – perhaps within the next three-quarters of a century. He based this estimate upon a modelling exercise with rather uncertain inputs. Other models have given rather different answers. Added to the expected effects of consumptive use, Bruce's estimate would imply that a third of the discharge is threatened. Clearly this will have to be one of the major research and political thrusts of the next few decades – to make these estimates firmer, and to protect water-levels, discharge, the rights of shoreline property owners, navigation and amenity in the Great Lakes system.

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*Comments were heard at the Workshop that the economic slowdown had meant that many planned thermal generating stations were being delayed, and might never get off the drawing board.

AGRICULTURE

Though farmland is scattered throughout the Great Lakes Basin, extensive arable land occurs only in southern Michigan, southern Ontario, and northern New York, with smaller areas in Wisconsin, Indiana and Ohio. Agriculture is mainly mixed farming, with extensive dairying and stock-raising. Specialty uses, such as the fruit gardens, vineyards and orchards of Niagara, and the tobacco fields of south-western Ontario, provide substantial extra income. Corn, winter wheat and soybeans, the dominant crops of the corn belt, are possible only in the southern two-fifths of the Basin because of severe winters or short growing seasons further north. Hay, oats and barley are possible throughout the Basin.

In recent decades hybrid strains have enabled the use of corn to be pushed progressively north-eastward into eastern Ontario and the Montreal Lowlands as a grain crop, as distinct from silage. The plant-breeders have done a great deal to enrich the agricultural potential of a difficult region – difficult because many of the soils are stony or barren, and because the climate is marginal for the most valuable forms of husbandry.

Contemporary agriculture is thus highly adapted to the present climate. Stresses such as the drought episodes common on the Prairies are unusual in the Basin. On the other hand crop losses from other causes are quite common. Thus late frost killed most the Ontario tobacco crop in June, 1972, and frost losses of fruit and vegetables are part of the risk farmers have to accept. Flooding of crops in low truck farming areas is also a hazard. But most farmers would agree that most of their problems lie elsewhere than in climate – most of them in the local banks.

On the other hand modern farm practice has moved steadily towards field irrigation. Summers are warm, and rainfall more capricious than in the cooler seasons. Thunderstorms may deluge one county and avoid another. In any case the water balance is such that irrigation will increase the yields of most crops if available at reasonable cost.

The predictions of the climate modellers, such as the recent EPA study (Rind and Lebedeff, 1984), imply that as the greenhouse warming of climate progresses soil moisture deficits in summer will rise, and the cost of irrigation water, whether from groundwater or from piped supplies, is likely to increase. Hence we appear to see two trends in progress – towards greater demand for water, when supply is likely to diminish or become more costly.

Nevertheless the upward trend of temperature, and towards longer growing seasons, should be good for farming prospects in the cooler parts of the Basin, where summer rainfall is often overabundant. This expected trend has not yet shown itself in the Lakes Basin.

The recent PLUARG studies sponsored by the International Joint Commission laid stress on the leaching of agricultural fertilizers and on the contribution of municipal sewage systems to phosphate loading of the Lakes – now declining, thanks to control of the latter source. Climate did not enter closely into these questions. But recent research at the National Water Research Institute (Lam, Schertzer and Frazer, 1983) has shown that the thermal stratification of Lake Erie, and hence phosphorus concentrations and oxygen depletion, are related to the travel of individual weather systems across the Great Lakes Basin. Indeed the threat to water-levels and discharge forced by climate change has very important implications for future water quality control. Nor should the contemporary contribution of the atmosphere to Great Lakes pollutant loading be neglected – notably the influx of nitrate and sulphate ions, and various toxic or biotically active substances.

THE REMAINING FORESTS

Major soil and forest boundaries cut across the Great Lakes Basin, under climatic control. The southern limit of the Boreal Forest runs near latitude 49 deg N. North of this line the forest dominants are black and white spruce, balsam fir, jack pine, larch and various willows, poplars, mountain ash and white birch. The southern margin of this forest, and its extensions along high ground well to the south, are the main home of the pulpwood cutters and processers. The northern edge of the oak-dominated Deciduous Forest runs from Toronto to Lake St. Clair, and thence across southern Michigan and Wisconsin. Much of this forest has been cleared. In between these two limits lies the Great Lakes – St. Lawrence mixed forest, dominated by sugar maple and beech, together with hemlock, white pine and a long list of deciduous hardwoods. Much altered by cutting and agricultural clearance, this area nevertheless supports some prosperous forest industries, and is extensively covered with second growth woodland.

These forests occupy distinct thermal zones (Hare, 1950; Hare and Ritchie, 1972). The borders between them follow isolines of annual net radiation income, and are also close to specific mid-summer isotherms. On the other hand the functional interdependence of climate and forest communities has yet to be demonstrated; we cannot pretend fully to understand them as ecosystems in quasi-equilibrium. In any case human exploitation has so altered the forest cover that it is now pointless to take the argument further.

Climate's impact on forestry operations is much more obvious. The industry relies on the well-known seasonal cycles for its field activities. Moreover climate presents at least three threats to the well-being of the forest stands on which the industry depends. Hot, dry weather is a commonplace of the climate, and is sometimes accompanied by lightning and high winds. Hence fire losses are a perpetual threat, especially in north-western Ontario and nearby Minnesota, Wisconsin and northern Michigan. Climate also influences the level of activity and rate of spread of many forest pests. And thirdly drought periods, admittedly infrequent in the Lakes Basin, may severely restrict growth in some seasons.

The changes in climate foreseen in the modelling exercises will tend to exacerbate all three of these hazards. Moreover they will slightly destabilize the ecosystems, favouring some species and habitats, discriminating against others. It is my impression that we have as yet little capability of predicting these changes, even when and if climatic forecasts achieve reasonable assurance.

NAVIGATION AND HYDROELECTRIC POWER

The implications of the foregoing account for navigation and power development are very clear. I have already commented on the potential downturn in discharge that is likely to come from increased consumptive use of water, and the probable further effect of climate change.

Because of the reliability and predictability (within limits) of the climatic inputs to the Great Lakes system, both hydroelectric installations and ships have been designed right up to the feasible limits implied by the present climate. Full use is made of the opportunities offered.

Before the opening of the St. Lawrence Seaway in 1959, only small, 4.5 m draught vessels could use the St. Lawrence River between Montreal and Lake Ontario. A few ocean-going ships (such as the Manchester Liners) regularly penetrated the Great Lakes, and more numerous canal vessels used the old waterway. The Upper Lakers, vessels built to the limit imposed by the dimensions of the locks in the Welland Canal and at Sault Ste. Marie, with 8 m draught, could not descend below Kingston. With the opening of the Seaway these Upper Lakers could reach the Gulf of St. Lawrence, just as ocean shipping could reach Duluth and Chicago. A new generation of vessels was built as bulk freighters, chiefly for petroleum products, grain and iron ore. These ships fit snugly into the Seaway, Welland and Soo locks with less than a metre to spare on either side, and between keels and lock-sills. Similar snug fits are achieved in harbours and berthing facilities.

In the same way the turbines at the generating stations at Barnhart Island and on the Niagara River assume the present abundant flow – though on the Niagara power has to compete with the need to maintain the spectacle of the Falls. At times of low discharge some control can be maintained over water levels in Lake Ontario, and hence over the flow into the penstocks at Barnhart Island.

There is no way, however, that present installations could maintain this happy situation if major decreases of flow were to occur because of consumptive use and climate change. The well-being of these two industries is hence dependent on our ability to supply extra water to the Great Lakes, if the predictions of decreased flow came true. And diversions from the

Hudson's Bay drainage, the only conceivable source, are bound to be highly controversial and expensive.

POWER

The Great Lakes Basin is remarkable for the high level of energy consumption, and for the diversity of its electric power sources. Coal-fired thermal stations line the shores of the Lake, especially Michigan and Erie, and also the Detroit River. Major hydroelectric stations are installed on the Niagara River (the Adam Beck and Robert Moses plants on the two sides of the gorge), and smaller installations are widespread on tributary streams. Downstream on the St. Lawrence very large stations are situated at Barnhart Island, between New York and Ontario, and within Quebec at Beauharnois (the latter being fed by a huge canal built on the embanked floor of an abandoned channel from Lake St. Francis to the Laprairie Basin). Nuclear generating stations are situated on the shores of several of the Lakes, and close to the Detroit River. Oil-fired and natural gas thermal stations also exist, but some have been mothballed or downplayed in recent years.

These generating stations make extensive use of the Great Lakes system. Coal and oil are transported to them, and fly ash from them, by ships. The fossil-fueled thermal stations use water as a coolant in their condenser systems, with high evaporative losses; about half the consumptive use of water goes into this process, with large increases planned for the future. Hydroelectric stations mix the water, and affect the ice régime up and down stream. Nuclear stations also use water for cooling purposes, returning much of it to the Lakes considerably warmer than before.

The major impact of climate on this industry, once power stations are designed to cope with direct environmental influences, is in the effect on consumption. Space-heating costs respond quite closely, and in a nearly linear way, to fluctuations of cool season temperatures, which affects oil and natural gas demand. Interannual variations of ±5 per cent in demand are commonplace. Cold spells in winter place strains on electric transmission and transformer systems and on natural gas delivery. Increasingly the same is true of hot spells in summer, because of air conditioning demand. In fact summer electric demand now exceeds that of winter in most U.S. cities in the southern half of the Lakes region, and the line separating summer from winter peaks is shifting northward. Needless to say if climate change raises temperatures, especially in winter, this balance (which is hard to predict) will be disturbed. There is at present a glut of power in the region, which makes these considerations marginal; but given the long-term nature of capital investment in the power industry they should not be ignored. Ontario, Michigan, Quebec and New York are in any case wired to exchange power. If peak loads come at different seasons it is to everyone's advantage that such exchanges prosper.

OTHER IMPACTS

Climate clearly has a major impact on recreation and tourism, which are big business throughout the Basin. Most aspects of outdoor recreation are affected, from sailing through skiing. The reliable warmth and sunshine of summer are among the reasons why the shorelines of the Great Lakes, and indeed of most lesser lakes, are extremely valuable properties – and also present severe environmental problems.

Climate also affects land and air transportation, to an extent well known to us all. The ice-storms and snows of winter are hazards to road transport, which insists on using systems of traction unsuited to icy surfaces. Fog and low ceilings affect aviation to a surprising extent. Commuter and local flying is especially liable to interruption or delay. Fog is a nuisance to shipping, as are spring ice-jams, especially in Huron and Erie. Early freeze-ups sometimes threaten to trap ocean-going vessels in the Great Lakes. And in that context there is another significant area of impact – the fisheries that those lakes do or ought to sustain.

Great Lakes fisheries are potential targets for future climate change, though this is a question on which I can say little. The recent history of these fisheries has been greatly disturbed by pollution problems, which are not climate related (except, perhaps, in the rôle played by storms in disturbing the bottom sediments, from which toxic substances may be released). The temperature and water quantity and quality changes implied by the forecasts of the greenhouse effect will certainly affect fisheries. This subject, already looked at by a few authorities, will need close attention in future.

OVERALL

What does this all add up to? In effect, to impacts on a gigantic natural system, the Great Lakes Basin, that supports the livelihood of a population greater than that of many famous nations. They live from the avails of an industrial system with no peers elsewhere, and upon a land surface that supports good agriculture, handsome and productive forests, and provides great beauty and satisfaction.

But the Basin also shows many signs of foolish mis-use. Widespread concern now exists about the quality of the Great Lakes water, and about the future proposals of increased demands upon it. International tension has arisen from these anxieties because Canada and the United States, in spite of the Boundary Waters Act of 1909, and of the International Joint Commission, have still not succeeded in achieving optimum management of this priceless asset.

This essay has tried to show that climate plays a key rôle in the use made of the Basin. The lives of the inhabitants are very closely adapted to it – to such a degree that very few ever realise the extent to which their hardware and software reflect that adaptation. Climate is taken for granted – and by being so overlooked, creates added costs for the inattentive.

If climate is about to change, as seems likely, Canadians and Americans should strive hard to foresee the details, and to adapt in advance. Discussions of future change are usually couched in gloomy or fearful tones. They have no need to be. If the inhabitants fully comprehend how they handle the present climate, which God knows takes some handling, they are well set to adapt to the future.

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PART TWO

Recommendations for Research

Recommendations for Research

The group recommendations in this section reflect the emphases of the papers, presentations, comments, questions and responses of a large group of experts representing a variety of disciplinary backgrounds; including climatologists, biologists, geographers, economists and limnologists. The research strategies discussed below reflect both the mix of disciplines present and also the widely shared and often expressed need for an interdisciplinary approach to the study of climate change in the Great Lakes Basin.

There are five foci for the recommended research strategies: the role of climate change scenarios and their limitations; the tight coupling of climate and climate change and the physical hydrologic system in the Great Lakes basin; the climate-ecological relationship(s); the climate-economy relationship(s); and the institutional framework for climate impact research as provided by public policy and decision-making.

As noted, above, the group represented several disciplines. In addition, one of the challenges that we faced in the group discussions was how to reconcile the priorities and viewpoints of the administrators ("doers") and the researchers ("thinkers"). Administrators and politicians often need to reach agreement - or at least a working compromise - quickly on courses of action; this often requires the use of professional judgement based on experiences rather than analysis in depth. Scholars tend to measure progress in terms of clarifying disagreements and distinctions, elaborating alternative approaches and exploring the implications of scientific uncertainty. The strategies discussed below reflect this tension - creative tension, we hope - between the urgency to formulate feasible projects and the imperative to retain a measure of healthy skepticism as the basis for scientific investigation.

1. CLIMATE CHANGE SCENARIOS[1]

Climate change scenarios derived from general circulation models (GCMs) provide possible distributions of temperature and precipitation for a doubling of CO_2 in the atmosphere for selected grid points. However, the future projections are uncertain and cannot be verified. The uncertainty of the projections is further compounded by the fact that GCMs use a rather coarse grid scale that does not provide enough data points to represent adequately even the regional features of a geographical entity as large as the Great Lakes Basin.

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[1] This subsection was drafted at the Workshop by a group consisting of H.G. Hengeveld (Rapporteur), B. Boville, K. Higuchi, M. Parry and J. Robinson.

A second approach to scenario development is the study of historical periods when climate was somewhat abnormal. Historical studies permit climate impacts to be placed in a broad context of economic and societal changes. However, the responses of physical, ecological and socio-economic systems to a single rare event may be quite different from those to a succession of such events - as would be experienced when the system tends to adjust to a new climatic regime.

It is generally held that the best strategy is to combine the two approaches. Agreement between GCMs and historical analogue predictions would increase the confidence that could be placed in both.

RECOMMENDATIONS

1

Scenarios derived from GCM simulations ($2 \times CO_2$) should continue to be the primary basis for climate impact research in the Great Lakes Basin.

2

Research should be undertaken to try to incorporate mesoscale lake effects into the GCM simulations.

3

Historical analogues of climate anomalies should be identified; the climate data for periods of anomaly should be made easily accessible to natural and social scientists wishing to study climate impacts. Sets of both climate and socio-economic data for periods of anomaly would provide an excellent starting point for climate impact analysis in a broad interdisciplinary framework (cf. the CLIMPAX project in the U.S.A.).

4

Natural and social scientists should try to estimate the threshold sensitivities and response functions of physical, ecological and socio-economic systems to climatic perturbations. This would provide valuable guidance to the Canadian Climate Centre on the types of climate scenarios data that should be developed as a high priority.

2. EFFECTS OF CLIMATE VARIABILITY AND CHANGE ON PHYSICAL SYSTEMS IN THE GREAT LAKES BASIN[2]

At the Workshop, participants attempted to determine gaps in understanding apparent at the present time in determining the effects of climatic variability on water levels and flows in the Great Lakes hydrologic systems, e.g. the estimation of the over-lake precipitation (P) and lake evaporation (E). These are two of the parameters which make up the net basin supply (NBS) of any lake ($NBS=P-E+R$) with R representing basin runoff which is probably the best known parameter.

When one examines the climate variability over the period of historical measurement (about 100 years) it can be seen that the period 1930–1960 was warmer than earlier or more recent periods, and that a high precipitation regime began about 1940 over the Great Lakes Basin. The average levels of Lake Erie (for example) during the period 1940–1980 were considerably higher than those during the period 1900–1940. However, the 1960's and 1970's were characterized by cooler air temperatures. This indicates that changes in precipitation and temperature do not necessarily coincide, and this complicates the simple proposition that climate warming necessarily equals low lake levels, since climate warming may well be accompanied by increased precipitation.

RECOMMENDATIONS

5

There is an urgent need for more research into the estimations of the climatic parameters affecting lake levels - precipitation over the lake, ice cover, evaporation from the lake and runoff from the land. The factors affecting the accuracy in estimating these parameters must be better understood before the effect of climate change on them can be determined.

6

Better models are needed of the thermal structure of the lakes and of air-lake interactions. At present, we can only speculate on the effect of climate warming on lake temperatures, and on the resulting changes in water and air quality (in the latter case, through changes in lake-breeze inversion characteristics).

7

Because of deficiencies in the understanding of vertical transfers of energy and in simulating boundary-layer processes on grids smaller than GCM grids one should apply current GCM CO_2 warming scenarios to the Great Lakes basin with caution and appropriate qualification.

[2] This subsection was drafted at the Workshop by a group consisting of M. Sanderson and F. Quinn (Rapporteurs), D. Etkin, H.G. Hengeveld, K. Higuchi, J.L Knox, D. Meisner, P. Pender, G.K. Rodgers, R. Street, E. Voldner and D. Witherspoon.

8

The time lags between changes in atmospheric variables and the resulting impacts on the Great Lakes system should be investigated. To this end, a regional climate monitoring system should be established. This type of research is required to provide early warning of large-scale climate change.

9

More research is needed on the impact of climate changes on
(a) air quality;
(b) acidic and toxic depostition in the Great Lakes basin;
(c) pollution from land runoff to the Lakes; and
(d) the release of toxic chemicals from the lakes to the atmosphere.

3. EFFECTS OF CLIMATE VARIABILITY AND CHANGE ON ECOLOGICAL SYSTEMS IN THE GREAT LAKES BASIN[3]

The thrust of the background papers for the workshop and the arguments put forward by the participants themselves was that there is an urgent need for better understanding of the effects of climate variability and change on ecological systems in the Great Lakes Basin. These effects could be detrimental or beneficial - in many cases we simply do not know. For example, we do not know the effects of shifts in air temperature on many species of fish, but the lowering of lake levels by a metre or more will affect wetland and other lakeshore habitats. The fringe of wetlands might be transposed downstream or downhill somewhat without major net effect, if the change in lake levels occurred graduallly. But if average temperatures increase, a more southerly type of wetland association would replace the present type.

In this connection, it should be emphasized that while the research proposed might provide illuminating results for the ecological research community, unless it were conducted in consultation with resource managers and climate modellers, it might not necessarily be immediately applicable to the management of the expected impact of the climate change.

RECOMMENDATIONS

10

Research is needed to establish the response functions of biological/ecological systems to various parameters of climate change. These response functions need to be studied with respect to:
- ecological productivity in some aggregate sense;
- geographic distribution of important species.

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[3] This subsection was drafted at the Workshop by a group consisting of H.A. Regier, M. Brklacich (Rapporteurs), T. Allsopp, B.W. Boville, M. Parry, A. Saulesleja, B.J. Shuter, R. Stewart, B. Stocks and T.H. Whillans.

Table 1.

Aspects of climate change	Agriculture Prod.	Agriculture Dist.	Forestry Prod.	Forestry Dist.	Fisheries Prod.	Fisheries Dist.	Wetlands Prod.	Wetlands Dist.
Temperature	YES	YES	YES	YES	YES	YES	YES	YES
Precipitation	YES	YES	YES	YES	NO	YES	NO	YES
Seasonal effects	NO	NO	YES	YES	NO	YES	NO	NO
Overall variability	NO	NO	YES	YES	YES	NO	NO	NO
Wind	NO	NO	YES	YES	NO	YES	NO	YES
Ice cover	YES	YES	YES	YES	NO	NO	NO	NO
Acidic deposition	NO	NO	NO	NO	NO	YES	NO	NO
Land/water interface	NO	NO	NO	NO	YES	YES	NO	YES
combined/ interactive effects	NO	NO	NO	NO	NO	NO	NO	NO

Knowledge and knowledge gaps with respect to ecological effects of climate change. The first word in each pair of words refers to productivity in some aggregate sense; the second word refers to geographic distribution of species. A "yes" denotes that for the next iteration of climate impact assessment, current understanding is sufficient. A "no" denotes insufficiency.

11

Table 1 summarizes the group's collective judgement on gaps in understanding and research opportunities. For various parameters of climate change (left-hand column), research priorities are identified with respect to agriculture, forestry, fisheries and wetlands. In some cases, of course, the effects may be unimportant; but in other cases, such as with respect to a change in ice cover, the effects on fisheries and wetlands may be substantial.

4. EFFECTS OF CLIMATE VARIABILITY AND CHANGE ON SOCIO-ECONOMIC SYSTEMS IN THE GREAT LAKES BASIN[4]

Interactions between climate change and socio-economic systems are very complex. Not only do external factors such as changes in world food prices play an overriding role in minimizing or exacerbating climate impacts on the economy of the Great Lakes Basin, but the values, aspirations, and organization of society change over the years, and this can alter climate-society relationships.

This area of research is still in its infancy. Much of the past and current research depends upon measuring the impacts of severe weather events on specific economic sectors so as to generate numerical (e.g. dollar) values related to impacts. This methodology is suitable to model short-run relationships (i.e. under assumptions of "other things being equal"), beyond which the complexities and interactions of the social system preclude any simple linearities. The larger questions of distinguishing between the impacts of short-term climate variability and long-term climate change have begun to be handled, but there continues to be a very strong tendency to extend into the social system the deterministic cause-effect type of physical models exemplified by crop-yield models. The long-term challenge in social science research is to develop approaches which preserve the rigour of these models, while also capturing the subtlety of our complex social, economic and political relationships.

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[4] This subsection was drafted at the Workshop by a group consisting of P. Timmerman and A.P. Grima (Rapporteurs), T. Choi, S.J. Cohen, J. Hall, D. Howe, V. Kinnaird, S. Lerner, D. Marchand, D. Phillips, W.E. Riebsame, B. Smith and G. Wall.

RECOMMENDATIONS

The research on the socio-economic impacts of climate change recommended below should help to close existing knowledge gaps, and also help to improve the social science component of climate impact studies.

12

Because the impacts of climate change on biophysical systems will express themselves in many cases in social and economic terms, research into the impacts of climate change on socio-economic systems is a high priority. We identify two general thrusts for this type of research, of which the first has a more immediate priority:

(a) Sector-by-sector research. This is required in order to establish the "building blocks" of any potentially affected socio-economic system. We cannot begin to ask the "what-if" questions if we have little understanding of the current patterns of interactions of climate and society;

(b) The second is research into developing alternative integrative frameworks. This would begin to get us to the point where we could move from the assumption "other things being equal" (ceteris paribus), to the more realistic assumption that many things do not remain equal – including social, economic, and political responses to the observed changes.

13

Recommendation 1 (b) will be the hardest to achieve, but without taking that step, we would probably not get an adequate model of the dynamics of the situation. Some of the following approaches might be tried:

- context analysis (e.g., historical case studies);
- the use of "risk and uncertainty" as a unifying concept;
- the generation and analysis of detailed socio-economic projections, simulations and scenarios (cf. climate change scenarios);
- the provision and dissemination of data on climate anomalies to social scientists and economists (see section on climate scenarios above);
- demographic research, including migration studies.

14

As noted, the first thrust should be research into sectoral assessments, including among others, the following sectors: agriculture, forestry, fisheries, recreation and tourism, energy, water supply and demand, transportation and housing. This research should focus on the examination of the sensitivities, vulnerabilities and linkages among and between these sectors. Social scientists could then seek to determine those critical thresholds in each sector where serious impacts begin to manifest themselves. These findings could then be given back to the physical scientists who could focus on modelling those thresholds.

15

In order to facilitate both sectoral research and the development of integrative frameworks, it is further recommended that we need to develop scenarios that deal with the following three sets of variables:

(a) physical conditions, including, for example, incoming solar radiation, the distribution and persistence of snow, and the expected *rate* of climate change;

(b) Socio-economic conditions, including critical thresholds, and elements susceptible to sensitivity analysis (e.g., prices, substitutions);

(c) The impacts of alternative energy-use patterns on climate. This would close the argument and would bring into play the policy implications involved in *prevention* and not just *mitigation* of the expected climate change. International collaboration is essential here (cf. the recent international convention on the protection of the ozone layer).

16

The interdisciplinarity, difficulty, and current sparseness of climate impact studies make "networking" imperative. The allocation of funds for networking, interactive working groups, and other methods of bringing workers in the field together should have a high priority. It is easier to integrate research approaches at the outset, than to carry on independent research which must later be forced into an integrative - and perhaps inappropriate - framework by necessity.

5. PUBLIC POLICY WITH RESPECT TO THE EFFECTS OF CLIMATE VARIABILITY AND CHANGE IN THE GREAT LAKES BASIN[5]

The previous sets of recommendations reflect the view that productive research informs and helps to set public policy. On the other hand, climate impact research strategies ultimately depend upon the priorities set by public policy. The fundamental difficulty in the policy area is the reconciliation of very different time frames of concern: policy decisions are characteristically made with regard to a few weeks, or at most, a few years; with climate change we are dealing with spans of fifty to a hundred years or more. Yet policy decisions we make today can influence the timing and severity of long-term climate changes, and may also put into place technologies - such as electricity generation - that will operate well into the future.

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[5] This subsection was drafted at the Workshop by a group consisting of G.A.McKay, H.E. Turner (rapporteur), W. Baker, B. DeCooke, H.L. Ferguson, F.K. Hare, H. Hill, R.E. Munn, W.M, Paterson, J. Robinson, J.R. Sandilands, R. Chen, S.A. Chagnon, P. Yee and B. Maxwell.

Another difficulty is that politicians often choose not to enunciate policy clearly, because that would restrict their freedom to manoeuvre. Too often scientific findings are seen simply as constraints on decision-making. Research findings may therefore be more useful if they are presented as a range of findings, since decision-makers must weigh many factors in their search for an optimum policy. In this regard, qualifications about the findings and their ranges of uncertainty need to be identified in order to avoid exaggeration or misinterpretation. By putting this "up front", scientists can help to maintain trust in their procedures and objectivity.

Alternative research strategies should be conceived as comprehensively as possible, so as to allow policy to be formulated in the context of all relevant factors, including external factors that may either bear on the issue or whose impacts may override the impacts of climate change. For example, the projected pressure on Great Lakes water from the Great Plains bears on decisions about optimal lake levels, while changes in foreign commodity markets may well override the local impacts of climate change on agriculture. One way to reduce this difficulty is to articulate wherever possible the potential policy implications of one's research findings, so as to alert policy makers to these implications.

The above considerations will improve the usefulness of climate impact research for policy makers, but it is also important to translate the findings of research in such a way as to deservedly gain a higher priority on the public policy agenda. The visibility and awareness of the potential impacts of climate change should be promoted in a variety of ways.

RECOMMENDATIONS

17

Climate impact studies with respect to the Great Lakes Basin should be undertaken within the context of public policy. Since the relationships between policy and climate research are not well understood, however, a study should be undertaken on the manner in which climate information has been used or has not been used in the formulation of policy, planning and regulatory decisions, and on the best means of contributing effectively to these processes. The differences in the timeframes for making decisions, and the timeframes within which climate changes occur also require more research.

18

For historical and other reasons, the Climate Planning Board and the Climate Advisory Committee predominantly reflect the interests of federal agencies that have the major responsibility for climate and climate-related services. An effective climate impact studies program demands administrative structures and institutional arrangements that permit other relevant interests to be represented or consulted. These structures and arrangements should be fostered.

19

The Great Lakes Basin is shared by two nations, as well as by two provinces and eight states. Interjurisdictional differences in both the process of policy formulation and the nature of the formulated policy may be very significant. A research program for the Great Lakes Basin should be developed as a joint Canada-U.S. activity. There is however, no properly mandated bilateral authority for sponsoring climate impact studies for the Great Lakes. These might conceivably be undertaken under the aegis of the International Joint Commission. Alternatively, several bilateral studies have been carried out jointly by the National Academy of Science (U.S.A.) and the Royal Society of Canada, on behalf of the two governments. These agencies might provide the broad, independent scientific umbrella desired for such undertakings, given appropriate authorization and funding. The Canadian Climate Planning Board is requested to examine ways in which an appropriate project can be formulated. In this connection, the success of IFYGL (International Field Year on the Great Lakes) and its organization should be noted.

20

In view of the potential pressure to divert Great Lakes water resources outside the basin, appropriate agencies of the federal/provincial/state governments are urged to commission an investigation into (i) the impacts of climate change and variability on the levels of the Great Lakes and connecting channels, and (ii) the socioeconomic consequences (benefits and costs) of such changes in flows and levels for the Great Lakes Region and North America and (iii) the role of water conservation in reducing the need of diversions and of coping with reduced flows and levels.

21

The visibility of climate impact studies could be enhanced in a variety of ways: keeping the public informed through publications, including the mass media; supporting an "activist climatologist" who would relate climate research to emerging public issues; keeping solid information ready so as to profit from opportunities to promote climate-related issues. In addition, the climatological research community should consider periodic meetings to discuss climate-related policy issues and keep them in public view.

PART THREE

Conclusions

Conclusions

The scientific analysis of CO_2-induced alterations in climate remains complex; the timing, the rate and degree of change are still debated. However, there is widespread agreement in the literature that a long-term increase in temperature is expected over the next few decades. The global and theoretical implications of such a warming and the attendant climate variability have been examined in many papers, conferences and monographs. The Canadian Climate Program workshop and this monograph focus on the assessment of climate impacts at the regional level where most of the policy and planning decisions need to be made.

Policy and planning may be expected to be complex and challenging in those regions where climate variability and change have a direct and immediate influence on the biophysical systems and the economy. The Great Lakes Basin provides an excellent example of this relationship: climate directly affects water flows, levels, wetlands, fisheries and forests; and navigation, hydropower generation, shoreline uses indirectly. The overview paper – and other papers presented at the workshop to be released as proceedings soon – show that climate change in the Great Lakes Basin will impact ecosystems and society substantially. The recommendations for research in this monograph represent a consensus of the interdisciplinary groups of scientists convened at the workshop. Although the techniques and approaches of climate impact assessment are still being developed, it is clear that in spite of the limitations of our understanding, we certainly know enough to begin to formulate a coherent research strategy.

From the recommendations of the five groups, we would like to formulate two overall conclusions derived from the group recommendations:

- We need to improve the biophysical basis for predicting climate change and its consequences, particularly with regard to increasing the spatio-temporal resolution. Climate change scenarios need to be more detailed with respect to time and space, biological response models need to be developed, and lake-atmosphere interactions need to be examined.

- On the social side we need to improve our understanding of how climate change and variability are expressed in political systems and economic markets. We need particularly to distinguish between the direct effects of climate on economic activities (i.e. under the assumption of other things remaining equal); and the same impacts examined in the wider and more dynamic context in which the economic, political and social frameworks also change. Research needs to be focussed on both challenges.

Perhaps the most general agreement at the workshop was that climate impact assessment research needed to become more interdisciplinary. The interaction between social scientists and biophysical scientists makes their respective work more relevant, more widely used and more generally applicable to policy issues. The enthusiasm at the workshop for interdisciplinary research on climate impacts augurs well for this fast expanding and exciting field of work.

APPENDICES

Appendix 1

Program of Workshop on
Climate Impact Assessment in the Great Lakes Basin:
Research Strategies

Eaton Hall, Seneca College,
King City, Ontario, February 8–9, 1985

DAY 1, FRIDAY, FEBRUARY 8, 1985

9:15 a.m. OPENING:

1. *H.L. Ferguson* on behalf of the Canadian Climate Program
2. *R.E. Munn* on behalf of the Institute for Environmental Studies

9:30 a.m. SESSION I:

The general field of climate impact assessment.

KEYNOTE ADDRESSES

1. Seven challenges of climate impact research: *W. Riebsame*, University of Colorado.
2. Methods for assessing the impacts of climate change on ecological/socio-economic systems: *M. Parry*, IIASA, Austria.

11:15 a.m. SESSION II:

Effects of climate on physical systems in the Great Lakes Basin.

1. Climate of the Great Lakes Basin: the importance of large-scale circulation anomalies and mesoscale climate features in studies of climate impacts: *J.L. Knox*, Toronto.
2. The effects of climate on physical systems: *M. Sanderson*, U. of Windsor, and F. Quinn, NOAA, Ann Arbor, Michigan.

1:30 p.m. SESSION III:

Impacts of climate on ecological/socio-economic systems
in the Great Lakes Basin.

1. The effects of climate on ecological systems:
   (a) On fisheries and wetlands: *H.A. Regier*, U. of Toronto, and *B.J. Shuter*, Ontario Ministry of Natural Resources.
   (b) On agriculture: *B. Smit*, U. of Guelph.
2. The effects of climate on socioeconomic systems: *P. Timmerman*, Institute for Environmental Studies.

3:30 p.m. SESSION IV:
Public policy KEYNOTE ADDRESS

Public policy with respect to the Great Lakes: *S. Changnon*, Illinois State Water Survey.

7:30 p.m.:
KEYNOTE DINNER ADDRESS

Climate impact in the Great Lakes Basin: an appraisal,
F.K. Hare, Trinity College.

8:00 p.m.: SESSION V:
Discussion groups

1. Climate change scenarios
2. Physical systems
3. Biological systems
4. Socioeconomic systems
5. Public policy

DAY 2, SATURDAY, FEBRUARY 9, 1985

9:15 a.m.: PLENARY: Progress reports by rapporteurs of discussion groups.
10:00 a.m.: SESSION VI: Second meeting of discussion groups.
1:30 p.m.: SESSION VIII: Final plenary: Approval of draft recommendations.

Appendix 2

LIST OF WORKSHOP PARTICIPANTS

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